MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 1, 2016/2017

EOP3026 – OPTOELECTRONICS DEVICES

(Nano, Optical)

8th October 2016
09A.M – 11A.M
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 7 pages with 4 Questions only.
2. Attempt all **FOUR** questions. The distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.

Question 1

(a) List two main applications for direct bandgap semiconductors.

[2 marks]

(b) (i) With the aid of an energy band diagram explain the basic principle of a light emitting diode (LED).(ii) Explain how applied forward bias voltage (V) allow the electrons become injected or diffused from n^+ side to the p^- side of an LED device.

[4+4 marks]

(c) In a p-type silicon semiconductor, using the Fermi-Dirac distribution, the probability that an acceptor level E_a for gallium (Ga) is occupied by an electron can be written as:

$$f_a = \frac{1}{1+\frac{1}{4}e^{(E_a-E_F)/k_BT}} \qquad (1.1)$$

where k_B is the Boltzmann constant, T is the absolute temperature in Kelvin and E_F is the Fermi energy. The factor 4 is due to the degeneracy factor of the acceptor. From Equation 1.1, the following Equation 1.2 can be obtained:

$$p^2 + \frac{pN_a}{4e^{\frac{\Delta E}{k_BT}}} - \frac{N_aN_v}{4e^{\frac{\Delta E}{k_BT}}} = 0 \qquad (1.2)$$

where p is the hole concentration in the valence band at absolute temperature (T) in Kelvin, E_F is the Fermi energy, $N_v = 2[2\pi m_h^* k_B T/h^2]^{3/2}$ is the effective density of states at the valence band, N_a is the acceptor concentration and $\Delta E = E_a - E_v$ is the ionization energy of the acceptor.

(i) Assume that $\Delta E = 0.0649\ eV$, $N_a = 1.20 \times 10^{15}\ cm^{-3}$, $N_V = N_{v,RT}$ $= 1.050 \times 10^{19}\ cm^{-3}$ at $T = 300$ K. Solve the value of p.

[Hint: For a quadratic equation of $x^2 + xN - N = 0$, the solution for x > 0 is $x = -\frac{N}{2} + \sqrt{\left(\frac{N}{2}\right)^2 + N}$]

[4 marks]

(ii) Suppose that $N_v(T) = N_{v,RT}\left(\sqrt{\frac{T}{300}}\right)^3$ at low temperature. Solve the value of p at $T = 90$ K.

[4 marks]

(iii)Based on the answer given in Question 1 (c)(i) and Question 1 (c)(ii), Comment on the hole concentration p at T = 300 K and T = 90 K.

[3marks]

Continued----

(iv)How can the doping concentration N_a be modified to ensure that this Ga-doped silicon semiconductor remain extrinsic within a much wider reasonable temperature range? [4 marks]

Question 2

(a) In a homojunction laser diode, what is the condition that allows lasing radiation to occur?

[5 marks]

(b) With the help of suitable graph describe typical optical power output vs. forward current for a LED and a laser diode.

[2 marks]

(c) In a double heterostructure diode, why is it important that the active layer is a thin layer?

[3 marks]

(d) What is the advantage of an AlGaAs/GaAs heterojunction?

[2 marks]

(e) (i) With the help of suitable diagrams, briefly describe the structure of a double heterostructure laser diode using two different bandgap semiconductors which are GaAs ($E_g \approx 1.4$ eV) and AlGaAs ($E_g \approx 2$ eV).

[2 marks]

(ii) Sketch a simplified energy band diagram (with clear labelling including the electron in the conduction band and holes in the valance band) for the double heterostructure Laser diode in the presence of a large forward bias. Explain where the lasing recombination takes place.

[3 marks]

(f) Consider an AlGaAs-based heterostructure laser diode that has an optical cavity of length 200 microns. The peak radiation is at 870 nm and the refractive index of GaAs is about 3.6. (i)What is the mode integer m of the peak radiation and the separation between the modes of the cavity?(ii) If the optical gain vs. wavelength characteristics has a full width at half maximum (FWHM) wavelength width of about 6 nm, how many modes are there within this bandwidth?

[4+4 marks]

Continued...

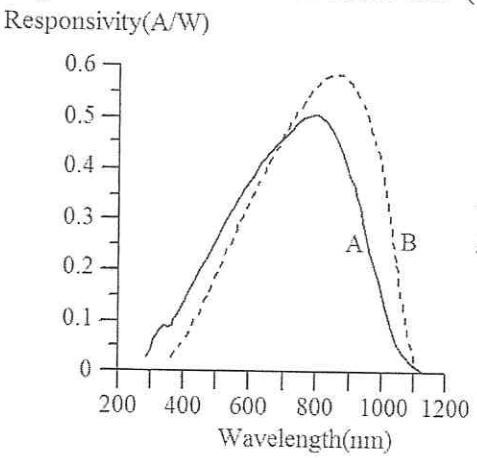
Question 3

(a) Describe **two** desirable properties of a photodetector. [4 marks]

(b) The responsivity of a photodetector will vary with changes in certain parameters. Name **two** of these parameters. [2 marks]

(c) Explain the **three** different ways to increase the Quantum Efficiency (QE) of a photo detector device. [3 marks]

(d) Consider two commercial silicon (Si) pin photodiodes, type A and type B, both classified as fast pin photodiodes, with their responsivity shown in FIGURE 3(d) below. The photosensitive area is 0.125 cm^2 (4 mm in diameter).



The responsivity of two commercial Si *pin* photodiodes

FIGURE 3(d)

(i) Explain why the photodiodes have different responsivity. [2 marks]

(ii) Calculate the photocurrent from each type of photodiode when they are illuminated with infrared light of wavelength 1000 nm and light intensity 1 μWcm^{-2}. [5 marks]

(iii) Calculate the quantum efficiency of each photodiode. [5 marks]

(iv) What is the quantum efficiency for an ideal photodiode? Sketch the responsivity versus wavelength curve for an ideal photodiode. [4 marks]

Continued...

Question 4

(a) What is solar constant or air-mass one (AM1)? [3 marks]

(b) (i) With the aid of a diagram describe the basic structure of a photovoltaic device.
(ii) What are the four basic steps in the operation of a solar cell?
[3+3 marks]

(c) A silicon solar cell of area 4 cm^2 is connected to drive a load R. It has the I-V characteristics shown in Figure 4(c) under an illumination of 1000 W m^{-2}. Suppose that the load is 20 Ω and it is used under a light intensity of 1 kW m^{-2}.

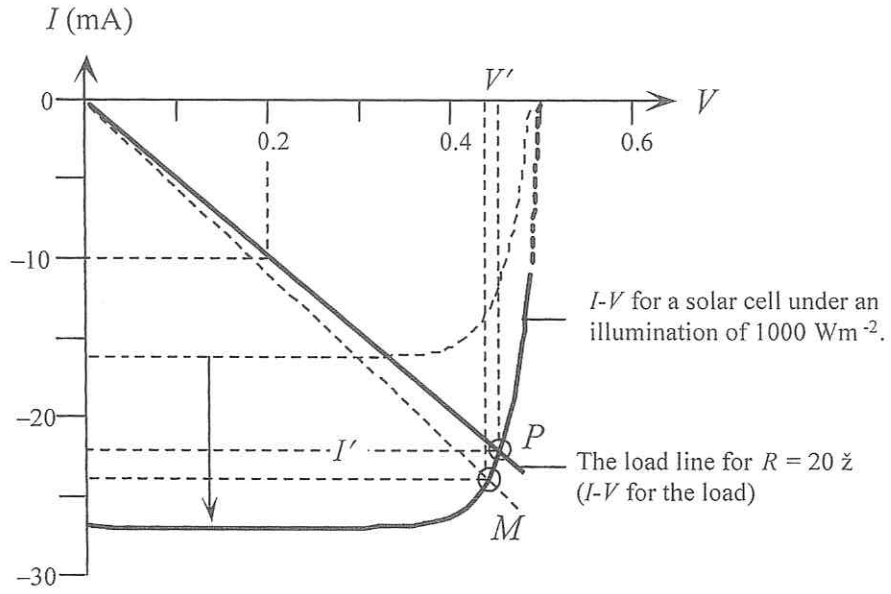


FIGURE 4(c)

(i) Calculate the power delivered to the load. [2 marks]

(ii) Calculate the input sun-light power. [3 marks]

(iii) Calculate the efficiency of the solar cell in this circuit. Comment on the efficiency of the solar cell. [3 marks]

Continued...

(d) Tandem cells uses 2 or more cells in cascade to improve the efficiency of a solar cell. With the aid of suitable diagram describe the working principle of Tandem solar cell.

[8 marks]

Appendix A
Useful constants:

Speed of light:	$c = 3.0 \times 10^{8}$ m/s
Electronic charge:	$e = 1.6 \times 10^{-19}$ C
Planck's constant:	$h = 6.63 \times 10^{-34}$ Js
Permittivity in vacuum:	$\varepsilon_o = 8.85 \times 10^{-14}$ F/cm
Permeability in vacuum:	$\mu_o = 4\pi \times 10^{-7}$ H/m
Free electron mass:	$m_o = 9.11 \times 10^{-31}$ kg
Boltzmann's constant:	$k_B = 1.3806 \times 10^{-23}$ J/K
Thermal voltage:	$V_t = kT/e = 0.0259$ V

Continued...

Appendix B – Useful Equations

$N_c = 2\left[2\pi m_e^* k_B T / h^2\right]^{3/2}$	$\tau_h = \tau_e = \dfrac{1}{BN_a}$
$N_v = 2\left[2\pi m_h^* k_B T / h^2\right]^{3/2}$	$\sigma = en\mu_e + ep\mu_h$
$n = N_c \exp\left[-\dfrac{(E_c - E_F)}{k_B T}\right]$	$D_h = \mu_h k_B T / e$
$p = N_v \exp\left[-\dfrac{(E_F - E_v)}{k_B T}\right]$	$D_e = \mu_e k_B T / e$
$np = N_c N_v \exp\left(-\dfrac{E_g}{k_B T}\right) = n_i^2$	$L_h = \sqrt{D_h \tau_h}$
$E_0 = -\dfrac{eN_d W_n}{\varepsilon} = -\dfrac{eN_a W_p}{\varepsilon}$	$L_e = \sqrt{D_e \tau_e}$
$V_0 = -\dfrac{1}{2} E_0 W_0 = \dfrac{eN_a N_d W_0^2}{2\varepsilon(N_a + N_d)} = \dfrac{kBT}{e} \ln\left(\dfrac{N_a N_d}{n_i^2}\right)$	$I = I_0\left[\exp\left(\dfrac{eV}{\eta k_B T}\right) - 1\right]$
$\varepsilon_n = \dfrac{h^2 n^2}{8 m_e^* d^2}$	$\varepsilon_n' = \dfrac{h^2 n^2}{8 m_h^* d^2}$

End of Paper